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DYNAMICS OF NH4 AND NO3 IN CROPPED SOILS IRRIGATED WITH WASTEWA--ETC(U)
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Each reference to NH_4 and NO_3 implies NH_4^+ and NO_3^- respectively.

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The objectives of this field study were 1) to obtain information on the dynamic behavior of wastewater NH_4^+ and NO_3^- in soils, 2) to determine the relative abundance of NH_4^+ and NO_3^- in soils receiving wastewater, and 3) to evaluate the seasonal effect on the fate of wastewater NH_4^+ applied to soils in a slow infiltration system. The study was conducted using an on-going test plot which contained two soil types and was covered with forage grass. Samples were collected in June and October to study the seasonal effect on the dynamic of N. The concen-

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tions of NH_4^+ and NO_3^- in the soil reached a daily, quasi-steady state condition. The seasonal effect on the relative amounts of NH_4^+ and NO_3^-, however, was significant. The vertical distribution of NH_4^+ and NO_3^- was similar but there was always more NH_4^+ than NO_3^-. The concentrations of both NH_4^+ and NO_3^- in soil profile were high at the surface and decreased with depth, consistent with the higher CEC, the slow movement of NH_4^+ in soils, and the higher organic matter content in the surface. Both NH_4^+ and NO_3^- concentrations were higher in the finer texture Charlton silt loam soil than in the coarser texture Windsor sandy loam soil.

PREFACE

This report was prepared by Dr. I.K. Iskandar, Research Chemist, L.V. Parker, Microbiologist, C. McDade, Physical Science Technician, of the Earth Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, LTC J. Atkinson, U.S. Army Reserve, and Dr. A. Edwards, Visiting Scientist, U.S. Army. LTC Atkinson provided statistical support for this project as part of his annual active duty.

Financial support for this research was provided by funds from Chief of Engineers Civil Works Project CWIS 31633, "Optimization of Automated Procedures for Design and Management of Land Treatment Systems" and CWIS 31297, "Nitrogen Transformation in Land Treatment." The manuscript of this report was technically reviewed by Daniel Leggett and James Cragin of CRREL.

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INTRODUCTION

In land treatment of liquid waste, N is applied in several ionic forms, such as NH_4, NO_3, and organic N.* The relative amounts of each form depend mainly on the degree and type of pretreatment. One goal of land treatment is to optimize N removal and to decrease NO_3 movement into groundwater. Since soil has a high affinity for NH_4 it is desirable to keep the applied N in the NH_4 form, both for plant uptake and to slow the rate of NO_3 formation.

The rate of wastewater application, and consequently the cost of renovating wastewater, is highly dependent on the amount of N that can be applied without increasing the level of NO_3 in groundwater. A high level of NO_3 in groundwater is undesirable because of its association with infant methomoglobinemia (blue-baby syndrome) and open water eutrophication.

The behavior of N in land treatment is affected by numerous physical, chemical and biological processes as well as soil environmental conditions. With this information, mathematical models for predicting of the fate of N applied in land treatment have been recently developed and are being tested (Iskandar and Selim 1978). However, testing these models requires field data on the rate of transformation of N species. The fact that in land treatment N is repeatedly applied in small amounts (most often weekly), in contrast to normal agricultural fertilizing practice, should make significant differences in the N transformation kinetics. Also, under land treatment the soils are often kept wet (near or above field capacity), and the water flow pattern, as well as the N transformation processes, will vary significantly from those under agricultural regimes. These differences makes it difficult to utilize the rate constants obtained from agricultural N experiments with land treatment models.

In the model developed recently by Selim and Iskandar (in press), plant uptake of N from the NH_4 and NO_3 sources was assumed to be a function of their concentrations in the soil solution. It was also assumed that the plants (forage grasses) had no preference for either form (S. Barber, personal communication). Therefore, to utilize such models it is necessary to determine the validity of these assumptions.

The objectives of this field study were 1) to obtain information on the dynamics of wastewater NH_4 in soils, 2) to determine the relative amounts of both NH_4 and NO_3 in soils during a one-week cycle of wastewater application, 3) to assess the transport of NH_4 and NO_3 in soils under field conditions, and 4) to evaluate the seasonal effect on the fate of wastewater NH_4 applied to soils in a slow infiltration mode.

EXPERIMENTAL DESIGN AND ANALYTICAL PROCEDURES

The study was conducted at the CRREL land treatment facilities in Hanover, New Hampshire. Two outdoor plots (test cells) were used, each 8.4 m square and 1.5 m deep, constructed of concrete, and filled with soils to their field bulk density in 1973. For detailed information on the construction and performance of the plots, the reader should consult Iskandar et al.

*Each reference to NH_4 and NO_3 in this report implies NH_4^+ and NO_3^-.

(1976). One cell contained Windsor sandy loam soil and the other Charlton silt loam soil. A mixture of reed canarygrass (*Phalaris arundinacea* L.), timothy (*Phleum pratense* L. var. "Climax"), and smooth bromegrass (*Bromus inermis* Leyss. var. "Lincoln") was seeded on 21 May 1973. However, during the course of the present study (summer and fall 1978) quackgrass (*Agropyron repens* L.) was predominant and Kentucky bluegrass (*Poa pratensis* L.) and reed canarygrass were present in lesser quantities.

Domestic wastewater was applied to the plots in variable amounts by spray irrigation during the period 1973 to 1976 (Jenkins et al. 1978). The application rates were 7.5 cm/wk from 1976 to 1977 and 5 cm/wk during the course of the present study. The 5-cm applications were made once per week over a 6-hr period and commenced on 16 May 1978. Table 1 shows selected analyses of the wastewater used.

Table 1. Analysis of applied wastewater for selected parameters.

	July	Oct	Mean June 77 to Mar 78 Cell 3	Mean June 77 to Mar 78 Cell 4
NO_3 (mg liter^{-1})	3.7	0.2	0.8	0.4
NH_4 (mg liter^{-1})	23.3	31.4	26.1	27.3
N(K)* (mg liter^{-1})	30.2	41.7	32.1	30.9
P(T)+ (mg liter^{-1})	7.0	7.4	6.4	6.0
C(O)** (mg liter^{-1})	43.3	-	69.0	70.0
Cl^- (mg liter^{-1})	35.4	32.8	31.1	31.0
pH	7.6	7.4	7.6	7.7
cond (µmho cm^{-1})	500	643	484	473
BOD_5 (mg liter^{-1})	-	-	44	-
SS(T)++ (mg liter^{-1})	-	-	129	146
SS(V)+++ (mg liter^{-1})	-	-	85	121

* Kjeldahl-N

+ Total phosphorus

** Organic carbon

++ Total suspended solids

+++ Volatile suspended solids

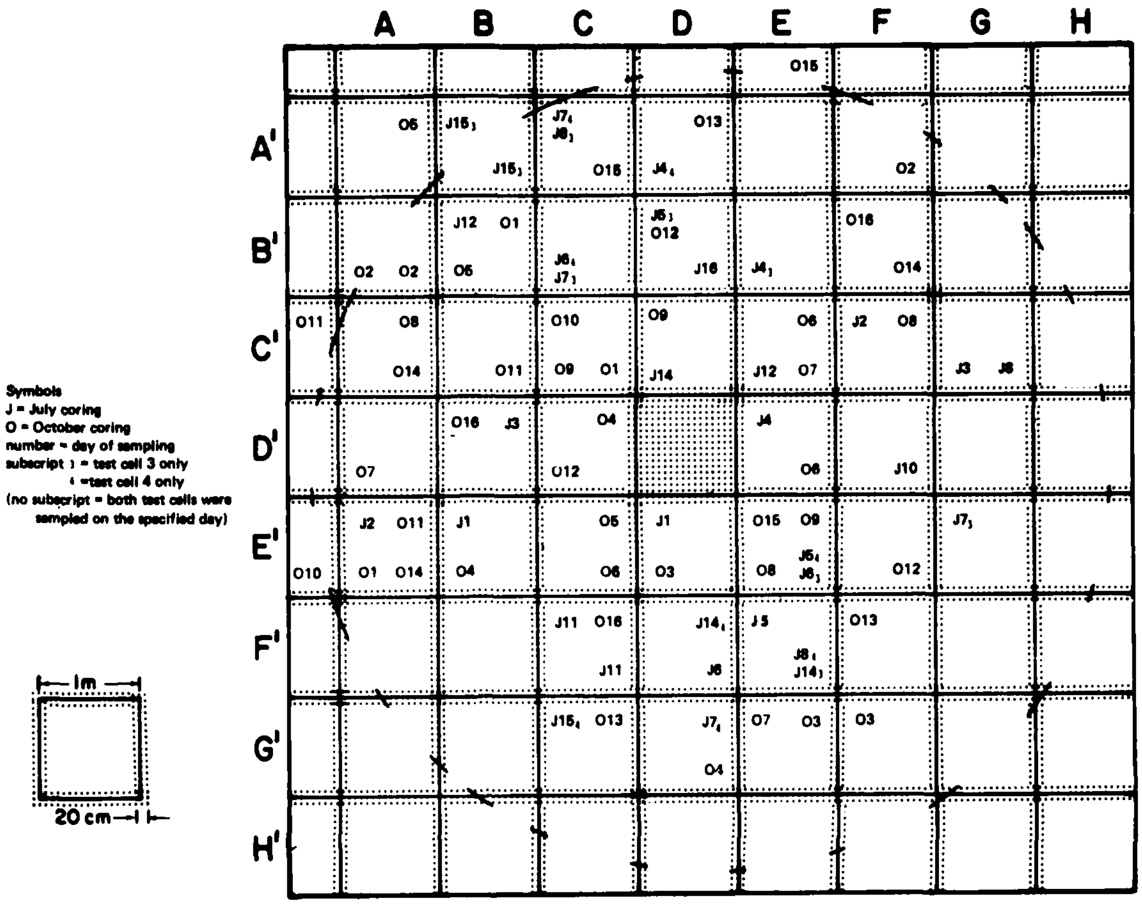

Figure 1. Test plot showing the location of randomly selected soil cores.

Each of the two plots was subdivided into 64 1-m^2 subplots for sampling (Fig. 1) with the spray head at the center of the grid.

The present study was conducted in June-July 1978 and was repeated in October 1978 to investigate the seasonal effect on the fate of applied wastewater NH_4. During June and July, two soil cores from randomly selected subplots were collected from test cells 3 and 4 on 14 days of a 16-day period (19-26, 28-30 June and 2-4 July). Each 1-m^2 subplot was visually subdivided into four equal areas for core sampling (Fig. 1). Soil cores were only collected from the sprayed areas. The soil cores were divided into five depth intervals (0-2.5, 2.5-7.5, 7.5-15, 15-30 and 30-60 cm) and were air-dried immediately after collection. In October 1978, soil cores were taken only from the 0-7.5-cm depth except on the third and tenth days when samples were collected down to 60 cm. Soil samples (5 g) were analyzed for soluble and exchangeable NH_4-N and NO_3-N by direct distillation and titration using the semi-micro steam distillation method (Bremmer and Keeney 1966).

Secondary wastewater was applied on days 1,8 and 16. In all cases, wastewater was applied immediately after collection of the soil samples designated for that day.

Statistical analyses were conducted with two Dartmouth Time Sharing System (DTSS) library programs: ANOVAR*** for analysis of variance and CELLMEAN*** for determination of the means and standard deviations. Missing data were calculated using the Yates method (Steel and Torrie 1966) considering day and depth simultaneously, or were estimated as a mean of all values at that depth if the Yates method produced a negative value.

RESULTS AND DISCUSSION

June-July Samples

Tables 2-5 show the concentration (meq-N/100 g soil) of NH_4 and NO_3 for the Windsor sandy loam (test cell 3) and the Charlton silty loam (test cell 4). As anticipated, the concentration of NH_4 was high in the topsoil and decreased with depth. In general, higher concentrations of NH_4-N than of NO_3-N were found in both soils during the study period. This was particularly true in the top 30 cm and could be attributed to several reasons, including 1) most of the N in the applied wastewater (>80%) is in the NH_4 form, 2) wastewater is applied weekly (5 cm/wk), and 3) most of the nitrified N is taken up by plants (sink) or leached to a lower depth.

Unexpected, relatively high values of NH_4-N were found deeper in the profiles, at 30-60 cm, in both soils. The maximum concentration was ≤ 0.30 and ≤ 0.07 meq/100 g soil in the Windsor sandy loam and the Charlton silty loam, respectively. This could be due either to movement of wastewater NH_4 during the present study or to movement of NH_4 from previous applications during late fall and early spring. Movement of NH_4-N in soil solution to depths of 150 cm in the same soils has been reported (Iskandar et al. 1976, Jenkins et al. 1978) and was related to soil type, amounts of NH_4 and wastewater applied, and length of time of wastewater application during the nongrowing season.

Figures 2-4 show the changes in NH_4-N and NO_3-N (mean of four analyses for each depth) at various depths with time in the Windsor and Charlton soils, respectively. The variation in NO_3 with time was much less than the variation in NH_4. The highest concentration of NH_4 was in the top 15 cm. Concentrations of NO_3 in the soil were low, as expected, because of leaching and plant uptake.

Table 6 summarizes the analyses of variance for NH_4 and NO_3 in the Windsor and Charlton soils as related to the effect of depth D, day of sampling T, soils S, variability among cores C', and analytical errors E. Since the selection of soil core location was random with no correlation of cores from day to day, the effect of core location should be negligible. Therefore, the full factorial model was modified to include the core effect by combining all the core interaction terms (C' = C + DC + TC + SC + DTC + DSC + TSC + DTSC).

The analyses showed that the variation between cores (the term C') at the same depth, soil, and day was significantly greater than the analytical error E, which was determined by replicate chemical analyses of the same

Table 2. Concentration of NH_4-N (meq/100 g soil) in Windsor soil (Test Cell 3), July 1978.

Day	Soil depth, cm: 0–2.5		2.5–7.5		7.5–15		15–30		30–60	
1	0.0557*	0.1014 ***	0.0482	0.0517	0.0152	0.0166	0.0122	0.0175	0.0047	0.0033
	0.0735**	0.0895	0.0521	0.0501	0.0422	0.0437	0.0309	0.0208	0.0069	0.0094
2	0.0514	0.3674	0.0474	0.0507	0.0404	0.0377	0.0165	0.0231	0.0056	0.0032
	0.0398	0.0445	0.0404+	0.037[illegible] +	0.0455	0.0416	0.0220	0.0282	0.0044	0.0025
3	0.0441	0.0420	0.0299	0.0175	0.0297	0.0198	0.0128	0.0169	0.0082	0.0092
	0.0587	0.0779	0.0445	0.0496	0.0396	0.0218	0.0263	0.0146	0.0039	0.0054
4	0.0555	0.0787	0.0674	0.0665	0.0705	0.0558	0.0179	0.0166	0.0134	0.0093
	0.1681	0.1337	0.0787	0.0766	0.0713	0.0803	0.0231	0.0233	0.0115	0.0102
5	0.1290	0.1280	0.0624	0.0614	0.0624	0.0579	0.0181	0.0196	0.0084	0.0051
	0.1133	0.1096	0.1129	0.1081	0.0494	0.0491	0.0175	0.0167	0.0061	0.0037
6	0.1467	0.1232	0.0608	0.0583	0.0816	0.0779	0.0220	0.0118	0.0025	0.0069
	0.2880	0.2715	0.0929	0.0834	0.0482	0.0478	0.0186	0.0164	0.0089	0.0056
7	0.0742	0.0606	0.0463	0.0535	0.0596	0.0426	0.0272	0.0262	0.0062	0.0097
	0.0723	0.0775	0.0645	0.0711	0.0505	0.0437	0.0756	0.0873	0.0087	0.0093
8	0.1362	0.1290	0.0684	0.0494	0.0534	0.0616	0.0185	0.0154	0.0188+	0.0185+
	0.0777	0.0801	0.0389	0.0316	0.0531	0.0550	0.0241	0.0202	0.0014	0.0023
10	0.1596	0.1664	0.0361	0.0437	0.0690	0.0618	0.0360	0.0348	0.0290	0.0204
	0.0553	0.0490	0.0705	0.0674	0.0311	0.0303	0.0210	0.0262	0.0124	0.0113
11	0.0572	0.0672	0.0542	0.0499	0.0466	0.0552	0.0187	0.0171	0.0111	0.0074
	0.2237	0.2204	0.0680	0.0560	0.0352	0.0373	0.0356	0.0540	0.0044	0.0052
12	0.0651	0.0608	0.0333	0.0389	0.0385	0.0274	0.0034	0.0047	0.0090++	0.0085++
	0.0933	0.0962	0.0404	0.0354	0.0544	0.0561	0.0307	0.0270	0.0124	0.0105
14	0.0511	0.0682	0.0396	0.0383	0.0194	0.0196	0.0264	0.0396	0.0088	0.0139
	0.1722	0.1660	0.0702	0.0453	0.0239	0.0225	0.0272	0.0274	0.0062	0.0070
15	0.0274	0.0254	0.0426	0.0513	0.0247	0.0237	0.0101	0.0122	0.0058	0.0074
	0.0433	0.0435	0.0488	0.0569	0.0202	0.0336	0.0227	0.0250	0.0124	0.0169
16	0.0849	0.1069	0.0566	0.0550	0.0494	0.0470	0.0169	0.0237	0.0140	0.0126
	0.1838	0.1920	0.0742	0.0632	0.0612	0.0649	0.0169	0.0144	0.0058	0.0072

* Soil core #1, top line for each day and depth

** Soil core #2, bottom line for each day and depth

*** Second column at each depth represents replicate determinations

+ Missing value calculated by Yates method (Steel and Torrie 1960, p. 139)

++ Missing value calculated as mean of all values at one depth

Table 3. Concentration of NO_3-N (meq/100 g soil) in Windsor soil (Test Cell 3), July 1978.

Day	Soil depth, cm: 0–2.5		2.5–7.5		7.5–15		15–30		30–60	
1	0.0335*	0.0191***	0.0352	0.0560	0.0086	0.0112	0.0120	0.0063	0.0049	0.0064
	0.0264**	0.0191	0.0187	0.0332	0.0142	0.0177	0.0074	0.0091	0.0012	0.0039
2	0.0463	0.0490	0.0136	0.0244	0.0161	0.0258	0.0338	0.0177	0.0078	0.0064
	0.0425	0.0478	0.0289+	0.0313+	0.0152	0.0216	0.0206	0.0122	0.0030	0.0037
3	0.0468	0.0321	0.0201	0.0235	0.0286	0.0241	0.0047	0.0054	0.0062	0.0045
	0.0320	0.0233	0.0220	0.0233	0.0299	0.0190	0.0175	0.0126	0.0076	0.0021
4	0.0350	0.0453	0.0332	0.0215	0.0167	0.0194	0.0062	0.0080	0.0039	0.0046
	0.0542	0.0647	0.0499	0.0387	0.0242	0.0225	0.0142	0.0128	0.0095	0.0093
5	0.0330	0.0235	0.0243	0.0387	0.0192	0.0169	0.0100	0.0100	0.0126	0.0103
	0.0377	0.0453	0.0499	0.0342	0.0239	0.0161	0.0181	0.0202	0.0049	0.0034
6	0.0231	0.0321	0.0272	0.0270	0.0393	0.0258	0.0072	0.0060	0.0032	0.0058
	0.0321	0.0415	0.0249	0.0285+	0.0181	0.0220	0.0059	0.0056	0.0089	0.0130
7	0.0348	0.0494	0.0253	0.0307	0.0165	0.0177	0.0087	0.0099	0.0084	0.0080
	0.0255	0.0315	0.0288	0.0290+	0.0181	0.0165	0.0134	0.0208	0.0113	0.0093
8	0.0272	0.0295	0.0237	0.0255	0.0218	0.0350	0.0103	0.0126	0.0067+	0.0060+
	0.0293	0.0396	0.0139	0.0146	0.0220	0.0241	0.0085	0.0069	0.0080	0.0105
10	0.0391	0.0426	0.0181	0.0194	0.0185	0.0177	0.0119	0.0169	0.0103	0.0070
	0.0162	0.0171	0.0262	0.0270	0.0210	0.0192	0.0087	0.0076	0.0056	0.0084
11	0.0406	0.0367	0.0330	0.0270	0.0196	0.0140	0.0103	0.0095	0.0037	0.0060
	0.0797	0.0955	0.0313	0.0321	0.0243	0.0264	0.0175	0.0161	0.0027	0.0012
12	0.0550	0.0367	0.0686	0.0618	0.0181	0.0204	0.0117	0.0169	0.0197+	0.0190+
	0.0422	0.0338	0.0210	0.0241	0.0293	0.0288	0.0264	0.0268	0.0144	0.0052
14	0.0241	0.0165	0.0190	0.0239	0.0161	0.0212	0.0111	0.0173	0.0041	0.0072
	0.0293	0.0272	0.0186	0.0134	0.0146	0.0145	0.0138	0.0192	0.0093	0.0080
15	0.0103	0.0178	0.0146	0.0220	0.0150	0.0080	0.0015	0.0054+	0.0019	0.0012
	0.0282	0.0222	0.0198	0.0200	0.0109	0.0161	0.0076	0.0045	0.0049	0.0080
16	0.0222	0.0190	0.0146	0.0148	0.0214	0.0214	0.0103	0.0140	0.0134	0.0078
	0.0455	0.0733	0.0336	0.0569	0.0205	0.0225	0.0140	0.0185	0.0192	0.0105

* Soil core #1, top line for each day and depth
** Soil core #2, bottom line for each day and depth
*** Second column at each depth represents replicate determinations

\+ Missing value calculated by Yates method (Steel and Torrie 1960, p. 139)

Table 4. Concentration of NH_4-N (meq/100 g soil) in Charlton soil (Test Cell 4), July 1978.

Day	Soil depth, cm: 0–2.5		2.5–7.5		7.5–15		15–30		30–60	
1	0.0616 *	0.0674 ***	0.0597	0.0465	0.0513	0.0569	0.0245	0.0297	0.0119	0.0099
	0.0511 **	0.0719	0.0393	0.0461	0.0371	0.0534	0.0216	0.0266	0.0115	0.0166
2	0.0688	0.0801	0.0554	0.0484	0.0349	0.0393	0.0309	0.0319	0.0267	0.0179
	0.1125+	0.1116+	0.0381+	0.0401+	0.0247	0.0271	0.0208+	0.0243+	0.0085	0.0078
3	0.5133	0.4818	0.0371	0.0290	0.0235	0.0268	0.0223	0.0212	0.0132	0.0163
	0.0449	0.0449	0.0400	0.0480	0.0325	0.0319	0.0365	0.0334	0.0102	0.0139
4	0.0777	0.0468	0.0593	0.0602	0.0606	0.0505	0.1510	0.1755	0.0210	0.0220
	0.1014	0.0843	0.0628	0.0647	0.0441	0.0494	0.0309	0.0379	0.0131	0.0184
5	0.0543	0.0512	0.0519	0.0583	0.0068	0.0202	0.0733	0.0651	0.0105	0.0126
	0.0587	0.0313	0.0799	0.0952	0.1125	0.1096	0.0241	0.0336	0.0145+	0.0131+
6	0.0657	0.0583	0.0946	0.1131	0.0550	0.0523	0.0231	0.0173	0.0181	0.0253
	0.0787	0.0927	0.0773	0.0770	0.1209	0.1127	0.0911	0.0904	0.0074	0.0097
7	0.0731	0.0742	0.0799	0.0845	0.0770	0.0816	0.0474	0.0301	0.0363	0.0439
	0.1277	0.1520	0.0585	0.0550	0.0470	0.0391	0.0496	0.0451	0.0218	0.0190
8	0.0760	0.0606	0.0585	0.0560	0.0902	0.0803	0.1333	0.1401	0.0433	0.0398
	0.0591	0.0453	0.0396	0.0303	0.0744	0.0721	0.0264	0.0358	0.0244	0.0289
10	0.1252	0.1318	0.0270	0.0309	0.0875	0.0906	0.0501	0.0593	0.0672	0.0575
	0.0925	0.1016	0.0676	0.0775	0.1014	0.1051	0.0550	0.0731	0.0528	0.0452
11	0.0287	0.0205	0.0752	0.0908	0.0579	0.0490	0.0307	0.0389	0.0338	0.0231
	0.0503	0.0470	0.0455	0.0354	0.0501	0.0602	0.0206	0.0266	0.0187	0.0249
12	0.0773	0.0556	0.0340	0.0266	0.0733	0.0663	0.0408	0.0505	0.0307	0.0220
	1.0539	1.1332	0.1018	0.1189	0.0373	0.0496	0.0332	0.0428	0.0313	0.0272
14	0.2740	0.2072	0.0338	0.0418	0.0288	0.0305	0.0385	0.0474	0.0470	0.0371
	0.0985	0.1129	0.0358	0.0315	0.0272	0.0270	0.0210	0.0216	0.0212	0.0165
15	0.0661	0.0799	0.0828	0.0721	0.1055	0.1071	0.0956	0.0789	0.0247	0.0229
	0.0826	0.0665	0.1735	0.1644	0.0387	0.0593	0.0243	0.0251	0.0177	0.0142
16	0.1421	0.1450	0.0917	0.1106	0.1261	0.1279	0.0414	0.0447	0.0144	0.0066
	0.1486	0.1589	0.0995	0.1051	0.0939	0.1059	0.0597	0.0698	0.0516+	0.0502+

* Soil core #1, top line for each day and depth

** Soil core #2, bottom line for each day and depth

*** Second column at each depth represents replicate determinations

\+ Missing value calculated by Yates method (Steel and Torrie 1960, p. 139)

Table 5. Concentration of NO_3-N (meq/100 g soil) in Charlton soil (Test Cell 4), July 1978.

Day	Soil depth, cm: 0–2.5		2.5–7.5		7.5–15		15–30		30–60	
1	0.0142*	0.0135 ***	0.0346	0.0431	0.0156	0.0142	0.0085	0.0115	0.0138	0.0091
	0.0385**	0.0422	0.0480	0.0369	0.0338	0.0490	0.0336	0.0509	0.0058	0.0041
2	0.0667	0.0652	0.0290	0.0433	0.0523	0.0551	0.0166	0.0135	0.0166	0.0122
	0.0336+	0.0343 +	0.0327+	0.0297+	0.0233 +	0.0238+	0.0058	0.0088	0.0081	0.0051
3	0.0178	0.0188	0.0309	0.0283	0.0439	0.0505	0.0187	0.0163	0.0105	0.0087
	0.0469	0.0540	0.0554	0.0356	0.0272	0.0725	0.0151	0.0137	0.0078	0.0070
4	0.0538	0.0358	0.0416	0.0589	0.0305	0.0482	0.0278	0.0255	0.0208	0.0124
	0.0441	0.0404	0.0447	0.0311	0.0198	0.0200	0.0082	0.0144	0.0146	0.0081
5	0.0377	0.0398	0.0770	0.0865	0.0777	0.0886	0.0354	0.0385	0.0087	0.0165
	0.0451	0.0342	0.0385	0.0517	0.0599	0.0593	0.0271	0.0257	0.0219+	0.0214+
6	0.0400	0.0593	0.0540	0.0499 +	0.0643	0.0496	0.0177	0.0165	0.0272	0.0299
	0.0278	0.0336	0.0463	0.0354	0.0387	0.0474	0.0290	0.0157	0.0049	0.0060
7	0.0245	0.0433	0.0402	0.0418	0.0323	0.0295	0.0225	0.0140	0.0073	0.0083
	0.0515	0.0669	0.0367	0.0309	0.0262	0.0210	0.0227	0.0428	0.0109	0.0124
8	0.0259	0.0239	0.0350	0.0319	0.0315	0.0315	0.0344	0.0398	0.0169	0.0142
	0.0558	0.0402	0.0737	0.0451	0.0208	0.0174	0.0389	0.0338	0.0041	0.0074
10	0.0878	0.0678	0.0387	0.0391	0.0381	0.0550	0.0192	0.0269	0.0260	0.0194
	0.0505	0.0725	0.0424	0.0583	0.0325	0.0323	0.0305	0.0449	0.0149	0.0159
11	0.0217	0.0220	0.0486	0.0348	0.0369	0.0581	0.0228	0.0205	0.0089+	0.0206
	0.0441	0.0494	0.0521	0.0344	0.0344	0.0245	0.0190	0.0299	0.0229	0.0179
12	0.0544	0.0488	0.0373	0.0311	0.0235	0.0328	0.0210	0.0210	0.0093	0.0105
	0.1772	0.1555	0.0517	0.0391	0.0358	0.0206	0.0218	0.0181	0.0255	0.0225
14	0.0174	0.0195	0.0579	0.0591	0.0307	0.0183	0.0253	0.0426	0.0217	0.0149
	0.0538	0.0484	0.0164	0.0154	0.0255	0.0188	0.0173	0.0118	0.0225	0.0309
15	0.0387	0.0330	0.0389	0.0235	0.0290	0.0305	0.0367	0.0222	0.0117	0.0124
	0.0325	0.0402	0.0770	0.0632	0.0126	0.0208	0.0163	0.0146	0.0049	0.0078
16	0.0279	0.0249	0.0587	0.0571	0.0529	0.0323	0.0183	0.0194	0.0081+	0.0071 +
	0.0332	0.0355	0.0262	0.0200	0.0256	0.0332	0.0227	0.0309	0.0052+	0.0047 +

* Soil core #1, top line for each day and depth

** Soil core #2, bottom line for each day and depth

*** Second column at each depth represents replicate determinations

\+ Missing value calculated by Yates method (Steel and and Torrie 1960, p. 139)

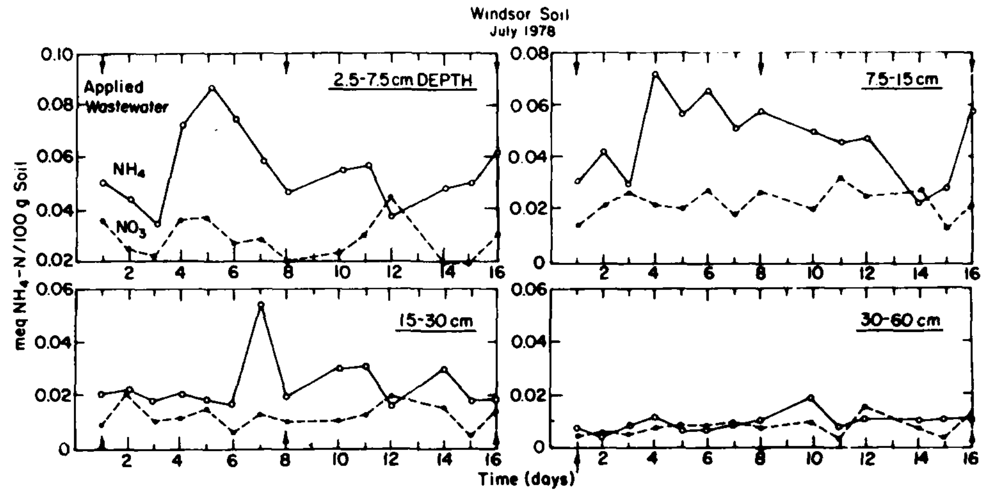

Figure 2. Changes in NH_4- and NO_3-N concentration at different depths in the Windsor soil over 16 days in July 1978.

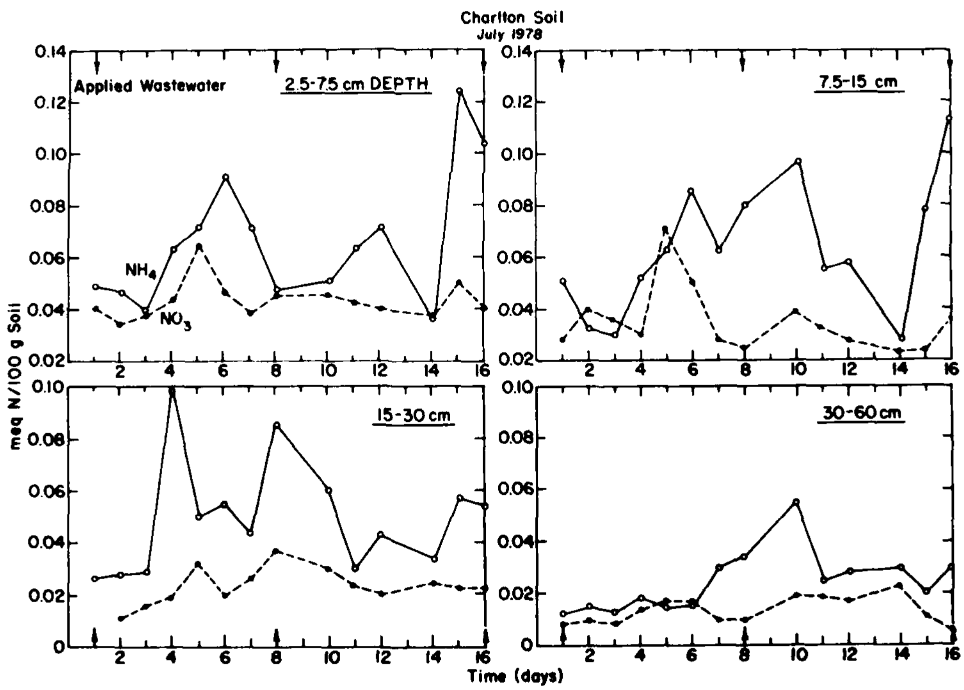

Figure 3. Changes in NH_4- and NO_3-N concentration at different depths in the Charlton soil over 16 days in July 1978.

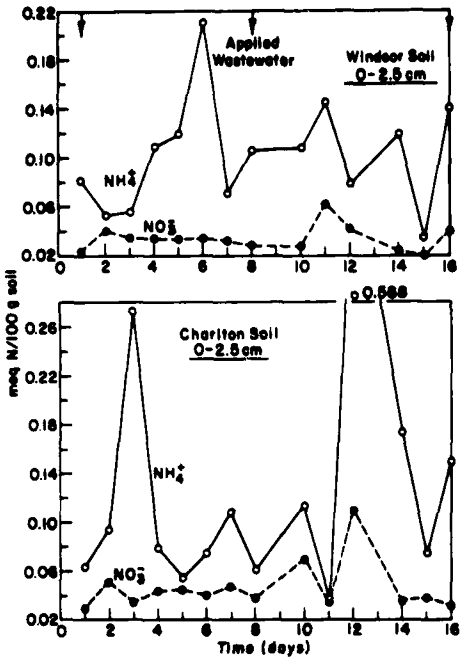

Figure 4. Changes in NH_4- and NO_3-N concentrations at 0-25-cm depth in Windsor and Charlton soils over 16 days in July 1978.

core. Since none of the interactions of depth x time, depth x soil, or depth x time x soil were significant, the data does not need to be treated separately by soil type, time, or depth for further analysis of variance. Each effect is independent of the others. The effect of depth was highly significant (0.1% level) for both soils and constant over time. The effect of soil type was found to be significant on the NH_4 distribution (2.5% level) and highly significant on the NO_3 distribution (0.1% level). The NH_4 and NO_3 levels were significantly higher in the Charlton silt loam than in the Windsor sandy loam. The effect of time was uncertain, appearing significant for the NO_3 distribution but not for the NH_4 distribution. This may be due to reapplication of wastewater in the middle of the experiment (the 8th day). This means that the statistical analysis should also have been done on a weekly, rather than on a 16-day, basis.

Since some samples were not collected during the second week, the data were arranged into two weeks of 5 days where week 1 consisted of days 3, 4, 5, 7 and 8 and week 2 consisted of days 10, 11, 12, 14 and 15. (Days 3 and 10 were two days after application.) The variables examined in this case were depth, day, week and soil. The analysis of variance (Table 7) indicated again that depth was highly significant (0.1% level) for both the NH_4- and the NO_3-N values, while soil was significant (5% level) for the NH_4-values and highly significant (0.1% level) for the NO_3-N values. Day and week again were not significant for the NH_4 values but day was highly significant (0.1% level) for the NO_3-N values, while week was not significant. An examination of Figures 2 and 3 indicates that the variation with day of the week is random and that there is no trend with time.

Figure 5 shows the depth distribution of the mean concentration of NH_4- and NO_3-N in the Windsor and Charlton soils. At any depth, the concentration of NH_4-N was much higher than that of NO_3-N. In the top 15

Table 6. Analysis of Variance, NH_4- and NO_3-N in Windsor and Charlton soils during July 1978. (Effect of soil type on the concentration of NH_4- and NO_3-N.)

		NH_4-N			NO_3-N		
Factor	D.F.*	Mean square	F	S.L.+ (%)	Mean square	F	S.L. (%)
Depth (D)	4	$1.7040\text{x}10^{-1}$	16.45	0.1	$1.7516\text{x}10^{-2}$	53.29	0.1
Day (T)	13	$9.1298\text{x}10^{-3}$	0.88	NS	$7.8495\text{x}10^{-4}$	2.39	1.0
Soil (S)	1	$6.0291\text{x}10^{-2}$	5.82	2.5	$1.7950\text{x}10^{-2}$	54.61	0.1
DT	52	$8.9486\text{x}10^{-3}$	0.86	NS	$3.3192\text{x}10^{-4}$	1.01	NS
DS	4	$2.8152\text{x}10^{-3}$	0.27	NS	$4.028\text{x}10^{-4}$	1.22	NS
TS	13	$1.1512\text{x}10^{-2}$	1.11	NS	$4.0219\text{x}10^{-4}$	1.22	NS
DTS	52	$1.0847\text{x}10^{-2}$	1.05	NS	$3.3659\text{x}10^{-4}$	1.02	NS
Core** (C')	140	$1.0356\text{x}10^{-2}$	151.01	0.1	$3.2869\text{x}10^{-4}$	8.67	0.1
Analytical error (E)	260	$6.8580\text{x}10^{-5}$					
	259++				$3.7894\text{x}10^{-5}$		

* Degrees of freedom

\+ Significance Level

** Core is the sum of C + DC + TC + SC + DTC + DSC + TSC + DTSC

++ After subtracting one D.F. for each calculated missing value

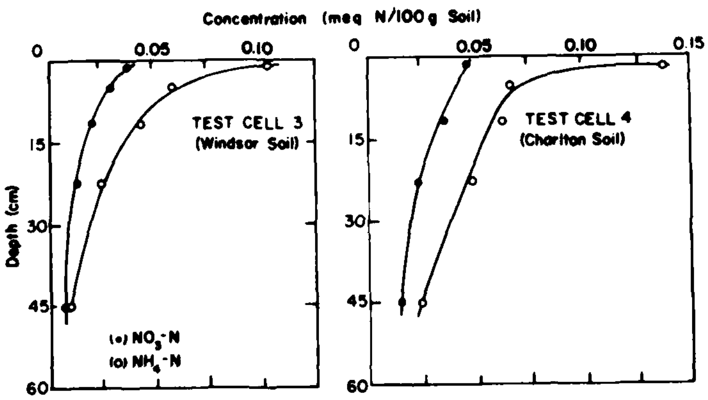

Figure 5. Depth distribution NH_4- and NO_3-N concentration in Windsor and Charlton soils in July 1978.

Table 7. Analysis of variance, NH_4- and NO_3-N in Windsor and Charlton soils during July 1978. (Effect of day when arranged in weeks.)

		NH_4-N			NO_3-N		
Factor	D.F.*	Mean square	F	S.L.+ (%)	Mean square	F	S.L. (%)
Depth (D)	4	1.2999×10^{-1}	9.28	0.1	1.2042×10^{-2}	37.41	0.1
Day (T)	4	7.4040×10^{-3}	0.53	NS	1.9301×10^{-3}	5.54	0.1
Week (W)	1	5.5079×10^{-3}	0.39	NS	1.4440×10^{-5}	0.04	NS
Soil (S)	1	6.5826×10^{-2}	4.70	5.0	1.5690×10^{-2}	45.00	0.1
DT	16	1.0661×10^{-2}	0.76	NS	3.0463×10^{-4}	0.87	NS
DW	4	8.9318×10^{-3}	0.64	NS	4.7593×10^{-4}	1.36	NS
TW	4	9.4822×10^{-3}	0.68	NS	3.5029×10^{-4}	1.00	NS
DS	4	8.5560×10^{-3}	0.61	NS	2.3102×10^{-4}	0.66	NS
TS	4	1.0567×10^{-2}	0.75	NS	5.5129×10^{-4}	1.58	NS
WS	1	1.2409×10^{-2}	0.89	NS	1.5252×10^{-4}	0.44	NS
DTW	16	4.4261×10^{-2}	1.02	NS	4.0632×10^{-4}	1.16	NS
DTS	16	1.0785×10^{-2}	0.77	NS	4.4522×10^{-4}	1.28	NS
DWS	4	5.9579×10^{-3}	0.42	NS	$4.1143c10^{-4}$	1.18	NS
TWS	4	1.9309×10^{-2}	1.38	NS	4.1042×10^{-4}	1.18	NS
DTWS	16	1.8620×10^{-2}	1.33	NS	4.3068×10^{-4}	1.24	NS
Core (C')**	100	1.4011×10^{-2}	180.16	0.1	$3.4864z10^{-4}$	9.81	0.1
Analytical error (E)	190	7.7771×10^{-5}	-	-			
	188++				3.5538×10^{-5}	-	-

* Degrees of freedom

\+ Significance Level

** Core is the sum of C + DC + TC + WC + SC + DTC + DWC + TWC + DSC + TSC + WSC + DTWC + DTSC DWSC + TWSC + DTWSC

++ After subtracting one D.F. for each calculated missing value

Table 8. Means and standard deviations of NH_4- and NO_3-N in the Windsor and Charlton soils during July 1978.

	NH_4-N, meq/100 g soil		NO_3-N, meq/100 g soil	
Depth, cm	Mean	S.D.	Mean	S.D.
0.-2.5	0.120	0.172	0.041	0.023
2.5-7.5	0.060	0.026	0.036	0.015
7.5-15	0.054	0.027	0.028	0.014
15-30	0.036	0.029	0.018	0.010
30-60	0.017	0.013	0.010	0.007

cm of either soil, NH_4-N concentration was more than twice that of NO_3-N. This could be explained by the leaching of NO_3 and the sorption of NH_4 by soils. As expected, there was a much higher concentration of NH_4-N in the surface soil than in the subsoil samples, largely due to higher surface cation exchange capacity (CEC) in the former. The trend with depth was the same, but to a much lesser degree, in the case of the NO_3-N distribution.

An attempt was made to use the Freundlich equation to relate the NH_4-N concentration to depth in each soil without regard to time. However, the deviation from the straight line regression was highly significant at the 0.5% level.

The mean NH_4-N concentrations in the top 7.5 cm of the Windsor and Charlton soils during the 16-day study in July 1978 were 0.047 ± 0.044 and 0.068 ± 0.012 meq-N/100 g soil, respectively. The mean NO_3-N concentrations in the Windsor and Charlton soils were 0.021 ± 0.014 and 0.032 ± 0.021 meq-N/100 g soil, respectively. Table 8 shows the mean and standard deviation of the NH_4- and NO_3-N concentrations in both soils with relation to depth.

October Samples

Tables 9 and 10 display the NH_4-N and NO_3-N concentrations in the Windsor and Charlton soils (test cells 3 and 4, respectively) for the October 1978 samples. Figure 6 shows the mean daily NH_4- and NO_3-N concentrations in the Windsor and Charlton soils (0-7.5 cm).

Analysis of variance (Table 11) of the October data for the 0-7.5-cm depth showed that the soil type has a highly significant effect on the NO_3-N concentration (0.1% level) but not on the NH_4-N concentration. This is similar to the results in July where soil was highly significant (0.1% level) for the NO_3 values and significant at the 2.5% level for the NH_4 values. The mean concentrations of NH_4-N for cores of the 0-7.5-cm depth in the Windsor and Charlton soils were 0.021 ± 0.010 and 0.031 ± 0.022 meq-N/100 g soil respectively; the July values for the same soil and depth were 0.067 ± 0.018 and 0.094 ± 0.055 meq/100 g soil. The October values are less than half of the July values. This may be due to higher uptake of NH_4

Table 9. Concentration of NH_4-N (meq/100 g soil) in Windsor and Charlton soils during October 1978. (Day 1 = 24 October 1978.)

		0-7.5cm		7.5-15cm		15-30cm		30-60cm	
Day	TEST* CELL	A	B	A	B	A	B	A	B
1	W	0.0317	0.0266						
	C	0.0408	0.0334						
2	W	0.0200	0.0233						
	C	0.0610	0.0624						
3	W	0.0402	0.0134	0.0138	0.0152	0.0101	0.0122	0.0006	0.0058
	C	0.0569	0.0904	0.0138	0.0134	0.0111	0.0103	0.0043	0.0085
4	W	0.0138	0.0258						
	C	0.0406	0.0476						
5	W	0.0227	0.0266						
	C	0.0179	0.0274						
6	W	0.0371	0.0237						
	C	0.0251	0.0338						
7	W	0.0039	0.0078						
	C	0.0016	0.0185						
8	W	0.0529	0.0377						
	C	0.0284	0.0169						
9	W	0.0068	0.0216						
	C	0.0140	0.0142						
10	W	0.0212	0.0080	0.0124	0.0130	0.0047	0.097	0.0017	0.0072
	C	0.0194	0.0249	0.0225	0.0247	0.0142	0.0099	0.0107	0.0082
11	W	0.0235	0.0216						
	C	0.0171	0.0206						
12	W	0.0142	0.0169						
	C	0.0015	0.0138						
13	W	0.0288	0.0115						
	C	0.0130	0.0165						
14	W	0.0305	0.0350						
	C	0.0150	0.0206						
15	W	0.0171	0.0185						
	C	0.0130	0.0237						
16	W	0.0233	0.0330						
	C	0.0134	0.0216						

W = Windsor sandy loam (Test Cell 3)
C = Charlton silt loam (Test Cell 4)

Table 10. Concentration of NO_3-N (meq/100 g soil) in Windsor and Charlton soils during October 1978. (Day 1 = 24 October 1978.)

DAY	TEST* CELL	0-7.5cm A	0-7.5cm B	7.5-15cm A	7.5-15cm B	15-30cm A	15-30cm B	30-60cm A	30-60cm B
1	W	0.0173	0.0245						
	C	0.0344	0.0377						
2	W	0.0185	0.0202						
	C	0.0344	0.0280						
3	W	0.0000	0.0206	0.0154	0.0124	0.0080	0.0035	0.0031	0.0023
	C	0.0408	0.0577	0.0037	0.0150	0.0000	0.0047	0.0000	0.0000
4	W	0.0284	0.0241						
	C	0.0309	0.0299						
5	W	0.0253	0.0247						
	C	0.0185	0.0299						
6	W	0.0183	0.0157						
	C	0.0208	0.0371						
7	W	0.0105	0.0268						
	C	0.0128	0.0274						
8	W	0.0264	0.0575						
	C	0.0154	0.0379						
9	W	0.0274	0.0185						
	C	0.0235	0.0358						
10	W	0.0253	0.0136	0.0060	0.0144	0.0049	0.0043	0.0089	0.0080
	C	0.0363	0.0309	0.0115	0.0140	0.0084	0.0025	0.0052	0.0078
11	W	0.0194	0.0212						
	C	0.0354	0.0264						
12	W	0.0206	0.0262						
	C	0.0293	0.0641						
13	W	0.0237	0.0146						
	C	0.0210	0.0264						
14	W	0.0200	0.0264						
	C	0.0313	0.0264						
15	W	0.0152	0.0121						
	C	0.0179	0.0290						
16	W	0.0237	0.020						
	C	0.0218	0.0346						

W = Windsor sandy loam (Test Cell 3)
C = Charlton silt loam (Test Cell 4)

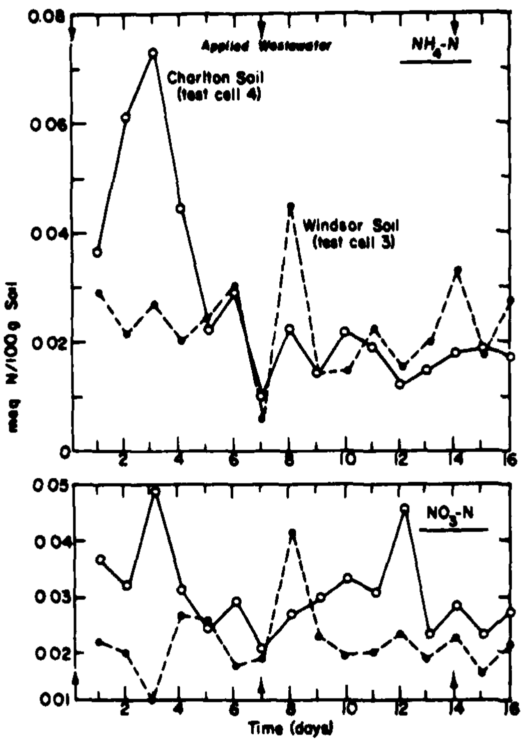

Figure 6. Mean daily NH_4- and NO_3-N concentration in Windsor and Charlton soils at 0-7.5 cm depth in July 1978.

Table 11. Analysis of variance, NH_4- and NO_3-N in 0-7.5-cm Windsor and Charlton soils during October 1978.

		NH_4-N			NO_3-N		
Factor	D.F.*	Mean square	F	S.L.+ (%)	Mean square	F	S.L. (%)
Day (D)	15	4.861	1.44	NS	0.826	0.98	NS
Soil (S)	1	3.032	0.90	NS	13.764	16.31	0.1**
DS	15	3.365	4.91	0.1**	1.330	1.58	NS
Analytical error (E)	32	0.686	-	-	0.844	-	-

* Degrees of freedom
\+ Significance level
** Highly significant

by plant roots which are more established at the end of the growth season.

A lower mineralization rate during October as compared to July, because of the temperature effect, may also contribute to the lower concentrations of NH_4 in October. The mean concentrations of the NO_3-N from the two soils at the same depths in October were 0.020 ± 0.007 and 0.031 ± 0.009 for the Windsor and Charlton soils, respectively. The July NO_3-N values are similar to those obtained for October. The mean concentration in the Windsor soil was 0.033 ± 0.008 and the mean concentration in the Charlton soil was 0.050 ± 0.011 meq-N/100 g soil.

Effect of Season (Temperature) on the Distribution of NH_4 and NO_3

Figures 6 and 7 show the mean NH_4- and NO_3-N concentrations for the two soils during October and July 1978. Only the data for the 0-7.5-cm layer is presented since the maximum temperature effect as well as the maximum NH_4 level is to be found in this surface layer. In general, much higher concentrations of NH_4-N were present in the July samples than in the October samples. The mean concentration for the 0-7.5-cm depth in July, without regard to soil type, was 0.081 ± 0.042 and in October was 0.026 ± 0.018 meq-N/100 g soil. The average temperature in July in the Hanover area was 20.6°C and in October was 6.8°C. It was expected that the higher mean temperature in July would be associated with a greater nitrification rate and faster disappearance of NH_4. High residual N from root decay and accumulation of NH_4 applied late in the previous season are thought to be the reasons for the higher NH_4 concentration in the surface layers in July. With the exception of the first three days in October for the Charlton soil (Fig. 6), the concentration of NH_4-N in both soils during the October sampling was less variable than in July. Analysis of variance (Table 12)

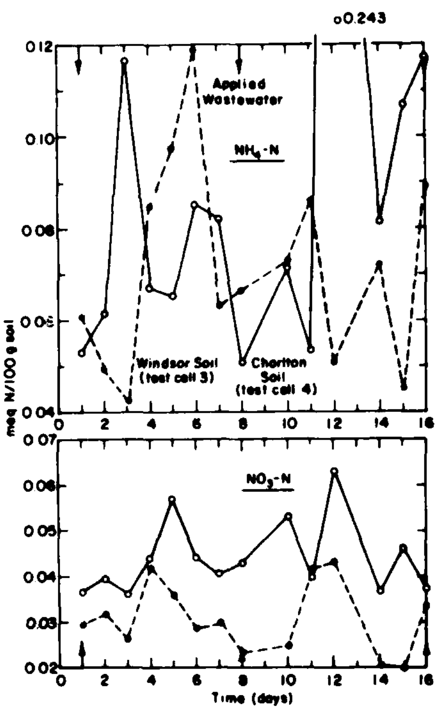

Figure 7. Mean daily NH_4- and NO_3-N concentration in Windsor and Charlton soils at 0-7.5 cm depth in October 1978.

Table 12. Analysis of variance, NH_4- and NO_3-N in 0-7.5-cm Windsor and Charlton soils during July and October 1978.

		NH_4-N			NO_3-N		
Factor	D.F.*	Mean square	F	S.L+. (%)	Mean square	F	S.L. (%)
Soils (S)	1	6.3012×10^{-3}	1.92	NS	3.4492×10^{-3}	11.17	5.0
Day (T)	4	1.7464×10^{-3}	<1	NS	3.7042×10^{-4}	1.20	NS
Week (W)	1	1.2800×10^{-5}	<1	NS	5.2531×10^{-6}	<1	NS
Month (M)	1	6.0808×10^{-2}	18.48	2.5**	3.4152×10^{-3}	11.06	5.0
ST	4	1.3708×10^{-3}	<1	NS	7.8389×10^{-6}	<1	NS
SW	1	2.4436×10^{-4}	<1	NS	3.0012×10^{-7}	<1	NS
TW	4	1.7042×10^{-3}	<1	NS	5.2533×10^{-5}	1.43	NS
SM	1	1.2688×10^{-3}	<1	NS	$9.0951 \times 10^{-}$	<1	NS
TM	4	1.4426×10^{-3}	<1	NS	$1.2928 \times 10^{-}$	<1	NS
WM	1	3.8948×10^{-3}	1.18	NS	4.6561×10^{-6}	<1	NS
STW	4	3.5908×10^{-3}	1.09	NS	7.6357×10^{-5}	2.08	NS
STM	4	1.9291×10^{-3}	<1	NS	3.0880×10^{-4}	8.43	0.1**
SWM	1	5.5112×10^{-3}	1.67	NS	1.2980×10^{-4}	3.54	NS
TWM	4	8.3941×10^{-4}	<1	NS	5.0532×10^{-5}	1.38	NS
STWM	4	3.2909×10^{-3}	61.42	0.1**	4.0774×10^{-5}	1.11	NS
Analytical error (E)	40	5.3582×10^{-5}			3.6650×10^{-5}		

* Degrees of freedom
\+ Significance Level
** Highly significant

showed that the effect of the month (temperature) on the NH_4-N concentration is significant (2.5% level). The higher NH_4 values in the July samples could be due to a higher mineralization rate as a result of the higher temperature.

The variations in NO_3 levels with time (days of the week after wastewater application) were much less than for NH_4 (Fig. 6 and 7). Again, analysis of variance indicated that the month, or temperature, was a significant factor (5% level). The NO_3 concentration, without regard to soil type, was 0.041 ± 0.013 meq-N/100 g soil for July and 0.025 ± 0.010 meq-N/100 g soil

for October. Analysis of variance also showed that soil type has a significant effect (5% level) on the surface layer NO_3-N concentration. In both seasons (July and October), NO_3-N concentrations were consistently higher in the Charlton silt loam than in the Windsor sandy loam. This is due to higher water holding capacity and a lower infiltration rate of the former soil. There was no significant effect of the week or the day of the week on NO_3-N concentration in the surface layer of both soils.

SUMMARY AND CONCLUSIONS

This study shows that the concentration of NO_3- and NH_4-N in soils irrigated frequently (weekly) with domestic wastewater seems to reach steady state conditions. In general, there was no significant change with time in the NH_4 concentration in surface soils. The NH_4-N concentration decreased with soil depth. At any time and depth, there was more NH_4 present than NO_3. The Charlton silt loam contained more NH_4 and NO_3 at all soil depths than the Windsor sandy loam although this difference wasn't always significant for the NH_4 values. The vertical distribution of NH_4 and NO_3 in both soils, however, is similar. There was a significant seasonal effect (month) on the distribution of NH_4-N in both soils; the concentrations of NH_4-N were much higher during the warmer month.

With a few exceptions, there were no significant changes in soil NO_3-N at any specified depth with time. As with the NH_4 distribution, soil depth was found to be the most significant factor affecting NO_3 distribution. The concentration of NO_3-N was high at the surface and decreased gradually with depth. The high NO_3-N concentration at the surface was related to the presence of a higher concentration of NH_4-N, favorable conditions for a higher rate of nitrification, and greater CEC in the surface soils to retain the NH_4. Also, NO_3-N concentrations were significantly higher in the Charlton silt loam than in the Windsor sandy loam. Temperature was a significant factor for the distribution of NO_3-N in both soils; the NO_3-N concentrations were higher in July than October.

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